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Sustainability indicators for run of the river (RoR) hydropower projects in hydro rich regions of India

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ABSTRACT

Any hydropower project whether mega, large or small is to be weighed for sustainability at the time of its inception. Without proper sustainability assessment, the project may face many problems during its construction or/and operational phase(s). Legally also, this aspect has been made mandatory in many countries across the globe to check the feasibility of the project from sustainability point of view beforehand. This study intends to emphasise sustainability of run of the river (RoR) hydropower projects in hydro rich regions of India where these types of projects are being undertaken on a large scale. In addition, this study has compiled a list of sustainability indicators which may be of use for policy makers and designers while planning RoR projects in hydro rich regions of India and similar regions throughout the world.

Contents

1. Introduction

India with a population of about 1.25 billion is one of the fastest growing economic powers of the world and envisages becoming a developed nation by 2020. This calls for rapid development of the country's power sector, especially hydropower sector where the growth has not been so satisfactory during the recent years. To bridge a large gap between demand and production of electricity, tapping of unutilised hydropower potential in a fast and sustainable way presents both an opportunity as well as a challenge. Run of the river (RoR) mode (with and without small storage) of power generation is considered to be a comparatively fast and sustainable

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mode of power generation as compared to storage or reservoir based projects mainly due to saving of submergence area and quite less dislocation of people in the former mode. This mode of power generation has become a favourite amongst most of the countries across the globe in general and developing countries in particular. However, there is no direct or standardised method of measurement or even assessment/estimation of the sustainability of a hydropower project.

'Sustainability' is a buzz word these days. But, it is a complex and multi-disciplinary term [1]. Many studies and a quantum of research work have already been undertaken to predict/list sustainability indicators of hydropower projects. However, majority of the work pertains to reservoir based hydropower projects. Minuscule literature is available which presents sustainability indicators especially catering to the RoR projects. Hence this study is an effort to bridge this gap and enlist indicators

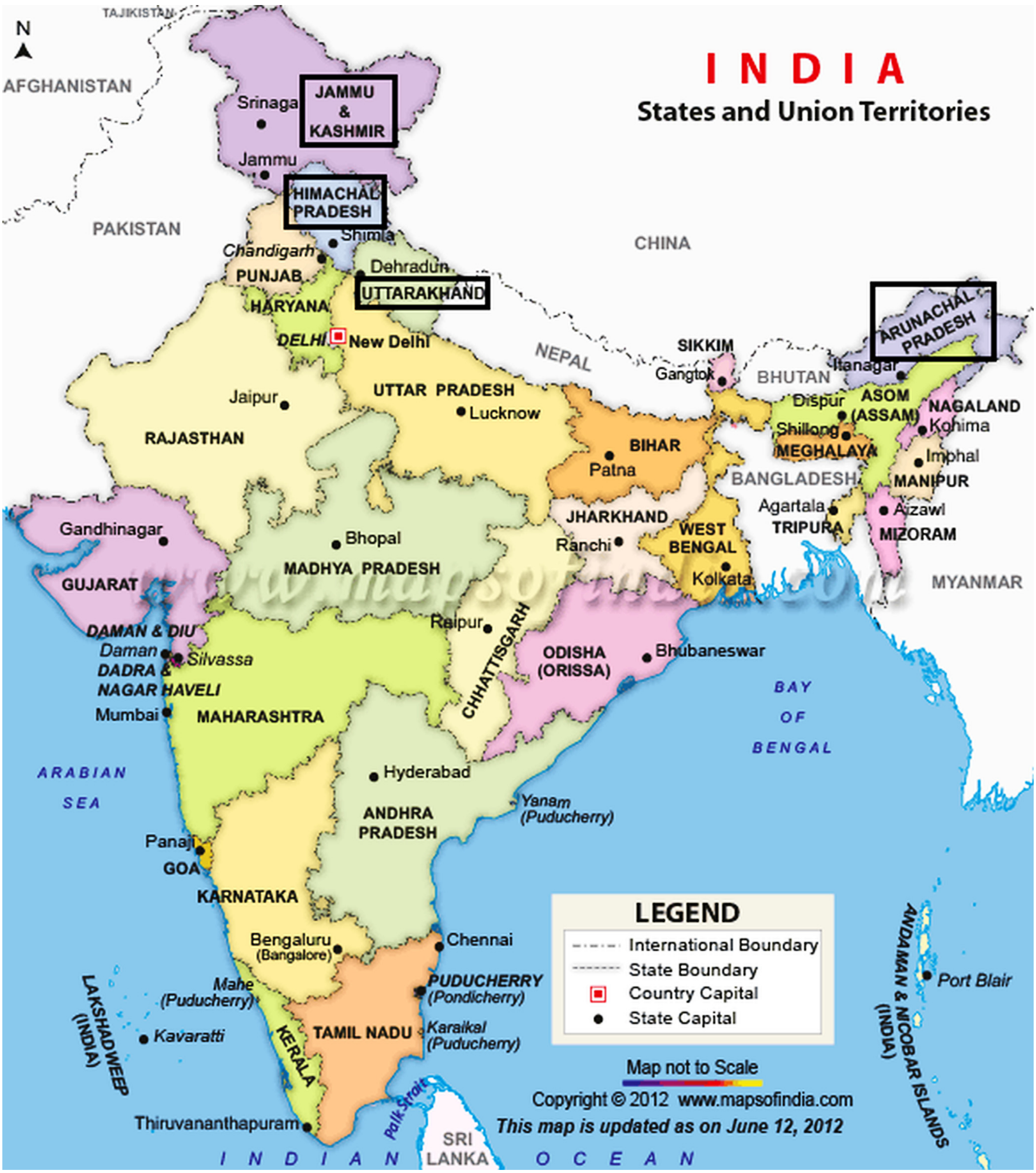

Fig. 1. Political map of India showing location of hydro rich states [4].

Table 1
Percentage share of hydropower potential in hydro rich states of India.

S. no.	Name of the state	Estimated hydropower potential (MW)	Percentage of total hydropower potential in India (out of 148701 MW)
1	Arunachal Pradesh	50328 [5]	33.8
2	Uttarakhand	26215 [6]	17.6
3	Himachal Pradesh	23000 [7]	15.5
4	Jammu & Kashmir	20000 [8]	13.4
		Total percentage	80.3

which predict or indicate sustainability of RoR large and small hydropower projects. This study has been presented keeping in view the hydro rich regions in India and other similar regions across the world.

2. Current hydropower scenario and hydro rich states in India

India is having a total installed power capacity of 228,721.73 MW from all energy resources (including renewable) [2]. Out of this, share of hydropower (excluding small hydropower projects) is 39,788.40 MW, i.e. only 17.39% (as on 30/09/2013). Total economically exploitable and viable hydropower potential in India is assessed to be about 84,000 MW at 60% load factor (148,701 MW installed capacity). In addition, 6780 MW in terms of installed capacity from small, mini and micro hydropower schemes have been assessed. Also, 56 sites for pumped storage schemes with an aggregate installed capacity of 94,000 MW have been identified. However, only 19.9% of the potential has been harnessed so far [3].

Four states (out of 28 states and 7 union territories) carry the lion's share (about 80%) of hydropower potential in India. These states are Arunachal Pradesh, Himachal Pradesh, Uttarakhand and Jammu & Kashmir. These states may be called 'Power Banks' of India. Fig. 1 shows the location of these states on political map of India (in rectangular boxes). Percentage share of hydropower potential in these hydro rich states has been shown in Table 1. All these states are situated in young and fragile Himalayan region. Hence development of hydropower projects in these regions poses harsh sustainability challenges.

3. Fillip for run of the river (RoR) hydropower projects

Many researchers in their works have reported that RoR projects are clearly more advantageous as compared to storage based projects. Goodland [9] outlined the advantages of RoR hydropower projects. These projects flood only small area relative to their output, interfere less with fish migration, are less prone to sedimentation and almost always less costly as compared to storage plants. Sarkar and Karagioz [10] commented on adverse effects of large-scale hydroelectric projects in India and Canada. They argued in favour of small-scale dams for sustainable development. However, they agreed that small hydropower projects have some limitations also. Egre and Milewski [11] illustrated that in all RoR projects, the absence of any sizable reservoir helps limit considerably both the social and the environmental impacts, as the river is not transformed into a lake. Furthermore, the flow pattern of the river remains essentially unchanged, which reduces downstream impacts of the project. Bakis and Demirbas [12] also felt that RoR mode is independent of size and has less impact on natural river flow ecosystems than large dams. However, no comprehensive and enough investigation had been done in this field, which requires further analysis to understand and to clarify it. Williams and Porter [13] compared large, small and pico-hydropower generation, focusing on the relative adverse environmental and social effects of each and their economic performances. Based on some economic investigations, the applicability of hydropower projects utilising schemes of different sizes was discussed. However, the research did not provide a firm conclusion, i.e. there was no 'best option'. Nautiyal et al. [14] analysed that many problems (like high capital cost, rehabilitation, resettlement of people, and geographical disturbance) are associated with large hydropower projects. Kaunda et al. [15] commented that RoR hydropower project possess economic as well as environmental advantages over other hydroelectricity generating systems of the same installed capacity.

Overall, RoR hydropower projects are considered more sustainable as compared to their storage based counterparts. These projects cause less ecological footprints per MW. This fact has been presented through Table 2 with respect to India's two large hydropower projects. The comparison has been done taking the aspect of power generation only.

Data presented in Table 2 clearly shows that for per MW of power generated, RoR type hydropower project is having very less submergence and quite less number of people are displaced. Hence, now there is an increasing trend for constructing RoR hydropower projects in place of storage projects, particularly in hilly regions, where big gradient becomes available in short distance. The difficulty in getting public and government's acceptance for large submergence areas for storage projects is one of the main causes for this trend [19]. Large social and environmental concerns related with storage projects are making them less favourite with people and governments.

In the recent times, some of the Indian state governments are encouraging development of RoR type hydropower projects only and in some cases, possible storage projects are being converted into 2 or 3 RoR schemes [20]. Hutong (3000 MW) and Kalai (2600 MW) in Arunachal Pradesh [20,21] and Devsari (252 MW) in Uttarakhand [22] are examples. These projects were proposed as storage schemes in the Pre Feasibility Reports (PFRs). However, later first two schemes were split and the third one was changed into RoR type by the respective state governments.

In May 2003, government of India had launched 50,000 MW hydropower initiative. Under this initiative, 162 projects have been

Table 2
Comparison between storage based and RoR hydropower projects.
Sources: [16–18].

Name of the project	Bhakhra	Nathpa Jhakari
Type	Storage based	Run of the river type
Installed capacity (MW)	1325	1500
Year of commissioning	1963	2004
Height of dam (m)	225.55	62.5
Length of reservoir (km)	96.56	2.5
Area of reservoir (km^2)	168.35	0.24
Area of land acquired (acres)	31191	395
No. of people affected	11777	3000 (approx.)
Resettlement and rehabilitation	Still pending	Completed

Table 3
Distribution of projects (based upon storage) under Government of India 50, 000 MW initiative.
Source: [23].

Type	Number of projects	Installed capacity (MW)
I. Run of river schemes	121	31626
II. Storage based schemes	41	16304
Total	162	47930

identified in 16 states of India having total installed capacity of 47,930 MW. These projects under this initiative are proposed to be taken up for execution during 11th and 12th five year plans, i.e. between 2007–2017. Out of 162 projects, 106 schemes aggregating to about 39,000 MW are located in already mentioned hydro rich four states namely Arunachal Pradesh, Uttaranchal, Himachal Pradesh and Jammu & Kashmir. All the preparatory works from feasibility report to detailed project report and also in many cases infrastructural development has already been done. Out of 162 projects, 121 projects are RoR type. Distribution of the 162 projects based upon the storage has been shown in Table 3.

4. Sustainability of the run of the river (RoR) hydropower projects

In earlier times, the economic consideration was the only criteria for any project development. Later on social aspect needed to be incorporated. It was felt that large environmental impacts from economic activities can easily lead to uncontrollable global disasters [24]. Hence, about 20–25 years ago, environmental considerations also found their place as an important aspect for successful development of any project. All these three aspects/dimensions combine to make a project overall sustainable. However these three aspects are conflicting. It is very difficult to design a project which is economical as well as have no environmental or social impact. Some environmental, social and economic impacts are bound to occur for development of a region.

4.1. Need for sustainability of hydropower projects

In India, about 80% of the total estimated power potential still remains untapped. The race is already ‘on’ to tap (earn) these hydro dollars by fast development of hydropower projects. The prospective developers are making beeline to sign MOUs and get the hydropower projects allotted. Central and state governments are also eager to sign these MOUs and earn the revenues from hydropower projects as fast as possible. In this race, the sustainability part is likely to be further lagged behind. If timely and effective measures are not taken, this margin will go on increasing and the situation may be soon out of control. Recent flash floods in Uttarakhand (India) on 16th and 17th June, 2013 have already given ample warning in this respect. While the rainfall is natural, the root causes which increased the human tragedy include unregulated, unsafe and unplanned infrastructure development along the rivers. Development of large number of hydropower projects in the fragile Himalayan zone without proper checks and balances, lack of transparent studies and un-democratic decision-making processes have fuelled the flood fury [25]. The rapid development of hydropower projects highlights the need for a more objective and comprehensive approach to quantify their impacts on the environment and society with regard to long-term sustainable development [26].

In above mentioned scenario, sustainability of hydropower projects has also become an important and un-avoidable issue. Most of the developing countries already have system of EIA (Environment Impact Assessment), which if followed properly can lead to a sustainable development of hydropower project. However, this process is merely considered as a hurdle in the development process. It is highly manipulated by developers in connivance with officials to get environmental clearance. Once the clearance is granted, most of the developers flout the norms with impunity. In India, small hydropower projects of installed capacity less than 25 MW have been exempted from EIA process [27]. Besides EIA exemption, this category of projects is offered many incentives (in terms of capital subsidy, less royalty, etc.) as these are put under renewable energy projects. Almost all small hydropower projects in Himalayan region are RoR type. Hence, sustainability of RoR hydropower projects in this capacity range is especially under suspense.

The need for sustainability analysis, using sustainability indicators has already been felt and expressed worldwide. It is a key requirement to implement and monitor the development of sustainable development policies, as required by Agenda 21 agreed at the UN Conference on Environment and Development in June 1992. The concept of sustainability is increasingly being adopted within the planning system to assess the value of development. Planning authorities have now started requesting data on the sustainability of a project as a part of planning application documentation [28].

5. Sustainability indicators

An indicator is something that provides a clue to a matter of larger significance or makes perceptible a trend or phenomenon that is not immediately detectable. Indicators should be SMART (Specific, Measurable, Achievable, Relevant and Time bound) [28]. These are the tools which should be used with wisdom and restraint. Only then, they can build support for needed changes and guide the actions of governments, international organisations, the private sector, NGO and other major groups towards sustainability [29].

Assessment of sustainability of a hydropower project also requires study and estimation of some indicators/parameters/factors which give an indication towards sustainability of that project. These indicators are called ‘Sustainability Indicators’ of hydropower projects. By visualising phenomena and highlighting trends, these indicators simplify, quantify, analyse and communicate otherwise complex and complicated information [30]. Establishing the set of appropriate sustainability indicators to be used in the assessment of sustainability is a crucial step in the research process [31,32].

5.1. Classification of sustainability indicators

Sustainability indicators can guide the actions of governments, international organisations, the private sector, NGO and other major groups toward sustainability [33]. Further, to put these indicators on a firm footing, their acceptance and utility are required to be approved by various stakeholders [34]. Broadly, sustainability indicators can be classified in two ways:

a) Classification on the basis of ‘three pillar concept’ of sustainability
b) Classification on the basis of measurability

5.1.1. Classification on the basis of ‘three pillar concept of sustainability

Social, economic and environmental criteria are three well known pillars of sustainability. Under this classification, some indicators can be classified into more than one criterion given the numerous inter-linkages among these criteria [35]. A course of action for economic development that disregards environmental and social criteria is likely to be unsustainable, as are courses of action that focus only on social or environmental criteria while disregarding the economy [36]. This classification enables one to understand marginal trade-offs among economic, environmental and social objectives of hydropower development [37]. There are three types of indicators under this classification:

Social indicators: These indicators are related to the life of local communities, their participation in decision making and acceptance

of the project by them. They account for social repercussions and long-term negative effects and benefits of hydropower projects [34]. In the recent past, this category of indicators has emerged as most important indicator of sustainability. These indicators should be selected and negotiated by the appropriate communities of interest [30].

Environmental or ecological indicators: These indicators are related to the environmental compatibility of the project with the surrounding territory and ecology [38]. These deal with the environmental issues which are vital for the environmental sustainability of the hydropower projects. In view of global concern about environment and ecology, national and international agencies which are funding hydropower projects are emphasising a lot on these indicators.

Economic indicators: These indicators represent the costs and the benefits of the hydropower project from the economic viability and profit point of view. As mentioned in Section 4, these indicators used to be the sole criterion for development of any project in the recent past. Still majority of developers and planners give top priority to this indicator. Generally technical/technological indicators are also merged with these types of indicators.

5.1.2. Classification on the basis of measurability

Being a multiple and conflicting criteria based parameter especially in case of hydropower development, measurement of sustainability is not a straight forward matter. There are two types of sustainability indicators on the basis of measurability:

Quantitative (tangible) indicators: These are the indicators which can be measured by a reliable unit. Different people have similar ideas about the amount of these types of indicators (e.g., area of submergence, power plant capacity, etc.). As these indicators are measured based on units of measurement, it is possible to compute the distance/difference between two alternatives with respect to quantitative criteria. Most of the economic sustainability indicators are quantitative type.

Qualitative (non-tangible) indicators: These are the indicators which are impossible to be defined or measured by a reliable unit. Different people have different ideas about these indicators (e.g., living standard of a community, visual impact, etc.). Due to lack of unit, it is not possible to compute the distance/difference between two alternatives with respect to these indicators [39]. These are generally expert dependent. Site visits and interaction with stakeholders may be required to access these indicators. Most of the social sustainability indicators are qualitative type.

Sustainability study of hydropower projects involves both types of sustainability indicators mentioned in above paragraphs.

5.2. Sustainability indicators for RoR hydropower projects

There are four main sources for selection of sustainability indicators for RoR hydropower projects viz. literature review, expert/professional opinion, site visits and perception survey in project areas. First source, i.e. literature survey is for general selection of sustainability indicators. However, the later three sources are useful for selection of sustainability indicators which are specific to a particular project or region.

Many researchers, national and international organisations have mentioned/listed sustainability indicators with respect to hydropower projects. Table 4 presents a brief overview of these studies. In-depth review of Table 4 indicates that the sustainability indicators mentioned by most of the studies are either generic or with respect to reservoir (storage) based hydropower projects. Very less number of efforts have been reported in the literature (that too with limited numbers of indicators) to list sustainability indicators exclusive for RoR hydropower projects.

Quantity of muck generated, impact of blasting, impact on cremation sites, CDM (Clean Development Mechanism) benefits, etc. are some of the indicators which are of special significance with respect to RoR hydropower projects. CDM could help to achieve the maximum utilisation potential of especially small hydropower projects more rapidly as compared to the current diffusion trend if supportive policies are introduced [51]. However, none of these indicators has been reported by researchers. Impact on cremation sites is an important social indicator from Indian context as majority of these sites are located on river/stream banks. One very important indicator in the present scenario, i.e. impact due to presence of other project in the vicinity (especially on same stream/river in case of cascade RoR projects) also has not been considered. Other important environmental indicators like ecological flow (environmental flow), diverted stretch of the river/stream, and aesthetics (visual impacts) have also not been mentioned by majority of researchers.

There are some other indicators which have evaded the attention of researchers though these may be applicable to both storage based and RoR hydropower projects. Some of them are impact due to transmission lines, impact of quarrying/mining operations and impact on ground water/natural sources of water, etc. Presence of already existing infrastructure (like access roads, transmission line networks, etc.) affects the economics of hydropower projects. However, this factor is also missing in almost all publications. Hydropower policies of the state and central government realise and establish rules for protecting the integrity of the environment and promoting sustainable development [52]. But, again this important aspect has been missed by other researchers.

Taking clues from the gaps and missing indicators from Table 4 (some of which have been mentioned in above paragraphs), Table 5 has been constructed. More indicators have been selected by studying DPRs of some RoR (large and small) projects, going through policy guidelines, undertaking site visits and interacting with stakeholders (project affected people, local public representatives, project proponents, government officials, etc.).

It is to be noted that sustainability indicators suggested in Table 5 form a generic list with respect to RoR hydropower projects. Some of the indicators suggested may not be applicable for a particular RoR hydropower project at all. In majority of RoR small hydropower projects, there is no reservoir impoundment. Also, an indicator may have different degree of importance for different hydropower projects. Public acceptance, displacement and rehabilitation issues are more pronounced in RoR large hydropower projects. Some of the sustainability indicators are inter-related, e.g. soil erosion and landslides, length of the diverted reach of the stream and impact on aquatic life. Hence, controlling or taking steps to improve one indicator can automatically improve the performance of related indicator. Onus is on planners and decision makers to pick the sustainability indicators and implement them as per sustainability need of the specific region and type of project.

The sustainability indicators suggested in Table 5 have been summarised according to number and type shown in Table 6. This table shows that total 49 sustainability indicators have been suggested for RoR large and small projects. Overall there are 25 qualitative and 24 quantitative indicators. In the category of social indicators, out of 15, there are 12 qualitative and 3 quantitative indicators. Hence, this aspect of sustainability needs in-depth analysis. Their evaluation or assessment needs help of expert opinion, site visits, questionnaire survey, interviews of local people and other stakeholders. There are equal numbers of qualitative and quantitative indicators (10 each) under environmental indicators. This aspect of sustainability can be assumed to be manageable to analyse. Further, under category of economic indicators,

Table 4
Hydropower sustainability indicators reported by other researchers.

Reference article	Social indicators	Environmental indicators	Economic indicators
Goodland [9]	Involuntary resettlement, co-operation of oustees and participation of all stakeholders	Land area required, construction of access roads, sedimentation and fish migration	Loss of agriculture
Sarkar and Karagioz [10]	Relocation of people, water related diseases and cultural heritage	Loss of biodiversity, bad impact on fisheries, effect on forest resources and land acquired for the project	Recreation, tourism and navigation
Afgan et al. [39]	Job generation, standard of living and community benefits	Emission of CO_2, NO_x and SO_2	Energy efficiency, investment per unit power and cost of energy per unit kW
Kaygusuz [40]	Effect of indigenous communities, water related diseases, construction of new roads, colonisation, undesirable traffic and immigrations, effect on cultural pursuits, migration to cities, job opportunities and lifestyle of local communities	Flooding of real estate and scenic areas, extinction of plant or animal species, migratory fish, deforestation, landslides and disturbance to natural habitats	Construction cost
Klimpt et al. [41]	Community participation, sharing project benefits, population displacement, public health, effect on heritage sites, public participation, sharing of developmental benefits and improving livelihood	Reservoir sedimentation, loss of biodiversity, water quality, fish passage, earthquakes, ecological flow, effect on vulnerable species and their habitats and flooded area	–
Bakis and Demirbas [12]	Increase of employment opportunities and living standard	Sediment deposition	Unit cost, maintenance and capital cost
Vera and Langlois [35]	Poverty, quality of life, education, demographic transition, indoor pollution, health and gender and age related implications	Climate change, deforestation, air, water and soil pollution	Job availability, industrial productivity, urban and rural development and all major economic activities
Evans et al. [42]	Public acceptance, displacement of people and animals from the homes/habitats, effect on agriculture pastures, access to regular irrigation water, recreational water sports and flood control	GHGs, land use requirement and siltation	Cost of electricity and efficiency of energy conversion
Kaygusuz [43]	–	Higher water temperatures, lower dissolved oxygen levels, altered pH levels, reduced habitat and species, diversity and reduced macro-invertebrate and native fish populations and productivity and climate change	Mitigation of flood and droughts
Carrera and Mack [34]	Innovative ability, water disposal, potential of conflict, participation in decision making, health concerns, familiarity with risks, catastrophic potential, functional impact and aesthetic impact	Potential reservoir eutrophication and sedimentation	–
Onat and Bayar [44]	Human health and agriculture	CO_2 emission, land use, air pollution, climate change and change in water quality	Unit energy cost, efficiency, water sport and tourism
Nautiyal et al. [14]	Resettlement and rehabilitation, land acquisition, transportation, communication links, irrigation, water supply, flood prevention, fisheries and tourism	Pollution and GHG emissions	Cost of electricity generation, energy payback time (EPBT), efficiency of energy conversion and gestation period
Kaunda et al. [15]	Involuntary settlement, destruction of settlement, loss of livelihood and cultural identity	Sedimentation, global warming (GHG emissions), inundation of land, change of landscape, loss of biodiversity, localised air and water pollution	–
Liu et al. [45] International Hydropower Association (IHA) [46,47]	Reduce poverty and enhance the quality of life, equitable distribution of the benefits of the project, effectiveness and ongoing compensatory and benefits, public health, impacts of displacement on individuals and communities, community acceptance and protection of cultural heritage	Air and water quality, waste management, downstream hydrology & environmental flow, public health, rare endangered species, passage of fish species, pest species within the reservoir (flora and fauna), health issues, impacts of construction activities on the terrestrial and aquatic environment and adoption of independently audited environmental management systems	Capital cost & recurrent cost, savings on GHG emissions and improved air quality and payback period
Vucijak et al. [48]	–	Biological indicators, morphological conditions, terrestrial habitats and water quality and fish fauna	Total construction and operation costs calculated per year, installed capacity (MW) and production capacity (GWh/y)
Maxim [32]	External costs (human health), job creation, social acceptability and external supply risk	Land use and external costs (environment)	Levelized cost of energy (LCOE), ability to respond to demand, efficiency and capacity factor (last three categorised under technological factors)
Dombi et al. [49]	New jobs and local income	GHG emission, land demand and other harmful ecological impacts	Increase in costs (LCOE)
Scannapieco et al. [50]	Employment and public acceptance	GWP100 (Global Warming Potential over 100 years), water, land consumption, underground resources, waste, effect on ecosystems (including flora and fauna), direct and indirect emissions, plant placement and hindrance, traffic and hazards	Capital and operation and maintenance cost and CED (Cumulative Energy Demand)
Rosso et al. [38]	Compensation fees/number of inhabitants, compensation fees/average pro-capite income, impact on multiple uses, local enterprises activities, marginal area, local employment and direct preference of stakeholder groups	Landscape quality and protected areas, hydrological risk, EF/Q_{mean} (ratio between environment flow and average discharge of river), $Q_{max\ der}/Q_{mean}$ (ratio between maximum discharge that can be derived by the plant and average discharge of river), $Q_{mean\ der}/Q_{mean}$ (ratio between average discharge that can be derived by	Operational costs, incentives, investment costs, compensation fees, average annual benefits, average annual gain, payback period and IRR (Internal Rate of Return). In addition, under technical aspects, parameters considered are length of river, net expected productivity, $Q_{mean\ der}$, altitude

Table 4 (*continued*)

Reference article	Social indicators	Environmental indicators	Economic indicators
		the plant and average discharge of river), water quality, water quantity and mitigation of impacts	of the intake, efficiency, head, plant typology and volume of structures
Morimoto [37]	Displacement and resettlement, living standard and health of communities	Impact on local biodiversity (flora, fauna, fish and invertebrate) and soil erosion	Net Present Value (NPV) and average generation costs per unit of generation

Note: Where not specified, categorisation of indicators has been shown as per authors' viewpoint.

Table 5
Suggested sustainability indicators for RoR hydropower projects.

Social indicators	Environmental indicators	Economic indicators
• Number of people displaced due to project (x, −) • Direct employment generation (x, +) • Public acceptance and participation in decision making (#, +) • Protection of cultural heritage (#, +) • Standard of living (#, +) • Corporate social responsibilities (#, +) • Effect on crop yield/fruit production (#, −) • Health hazards due to air, water or noise pollution (#, −) • Conflicts between local people and migrant workers (#, −) • Cracks in houses, damage to land due to blasting/other project operations (#, −) • Change in social values (#, −) • Impact on transport and communication facilities (#, +) • Wastage of time, movement restrictions and disturbance in study/other works due to project operations (#, −) • Effective/efficient utilisation of LADA (Local Area Development Authority) fund (x, +) • Impact on cremation sites (#, −)	• Quantity of muck/debris generation and disposal (x, −) • Land area acquired for the project (x, −) • Reservoir impoundment (x, −) • Length of diverted reach of the stream (x, −) • Quantity of silt in stream (x, −) • Emission of GHGs (x, -) • Air quality (air pollution) (x, −) • Water quality (water pollution) (x, −) • Noise pollution (x, −) • Existence of national park/wildlife century within 10 km aerial distance from the project site (x, −) • Soil Erosion (#, −) • Impacts due to transmission line (#, −) • Quarrying/mining operations (#, −) • Impact on aquatic life (#, −) • Impact on terrestrial animals and birds (#, −) • Natural hazards like landslides, cloudbursts, earthquake etc. (#, −) • Impact on ground water/natural sources of water (#, −) • Climate change concerns (#, ±) • Impact due to presence of other hydropower project in the vicinity (#, −) • Visual impacts (#, ±)	• Capital cost and recurrent cost (x, −) • Hydropower policies of state and central governments (#, ±) • Gestation period (x, −) • Payback period (x, −) • Generation cost /unit (x, +) • Accessibility of the project from existing road (x, −) • Length of transmission line (x, −) • Impact on tourism (#, ±) • Impact on trade, commerce and industry (#, ±) • CDM benefits (x, +) • Net generation efficiency (x, +) • Cost-benefit ratio (x, +) • Average annual availability of project for generation (x, +) • Resettlement and rehabilitation cost of project affected people (x, −)

Note: (x)=Quantitative, (#)=Qualitative, (+)=Possibly positive impact on sustainability or directly proportional to sustainability, (−)=Possibly negative impact on sustainability or inversely proportional to sustainability, (±)=May be positive or negative impact on sustainability.

Table 6
Summary of number and type of suggested sustainability indicators for RoR hydropower projects.

Social indicators (15)		Environmental indicators (20)		Economic indicators (14)		Total number of sustainability indicators=49	
Qualitative (#) 12	Quantitative (x) 3	Qualitative (#) 10	Quantitative (x) 10	Qualitative (#) 3	Quantitative (x) 11	Qualitative (#) 25	Quantitative (x) 24

out of 14, there are 3 qualitative and 11 quantitative indicators. Hence this aspect is comparatively easy to analyse and assess. Assessment, quantification, evaluation and ultimately aggregating sustainability indicators to form an index are not under the purview of this study.

6. Discussion

Due to present awareness amongst people about their rights and emphasis of national and international funding agencies on protection of environment, development of a non-sustainable hydropower project has already become a distant dream. As a chunk of hydropower capacity is yet to be undertaken in India and other developing countries, it is high time that the aspect of sustainability finds its due place in hydropower policies and guidelines. Hydropower energy planners should endeavour to frame guidelines and policies in such a way so that economic viability of hydropower projects is not marred by stringent social and environmental concerns. This is more important in view of major participation of private sector in this field.

Suggested sustainability indicators in this study for RoR hydropower projects may help policy makers and planners to select and imbibe the region specific sustainability indicators in feasibility and detail project reports of the hydropower projects. These may be also helpful in developing some decision making tool for identifying non-sustainable projects and allowing/encouraging a particular range/type of RoR hydropower projects in a particular region. Further, strict observation of these indicators during execution and operation stage is very important to be ensured. This will certainly help in development of sustainable RoR projects which are environment friendly, socially acceptable and economically viable.

7. Conclusion

In order to meet the ever growing demand for energy and rocketing fossil fuels prices, development of hydropower projects is need of the hour particularly in developing countries. But, it is equally important to fulfil this need in a sustainable way. RoR mode of hydropower generation has become quite popular throughout the world in the recent times. It is a general perception that this mode is more sustainable as compared to storage based hydropower projects. Sustainability of RoR hydropower projects involves many parameters or indicators. Identification, application and monitoring of these sustainability indicators are imperative for long term sustainability of RoR hydropower projects.

The sustainability indicators suggested in the study may be helpful for policy makers and decision takers to identify specific RoR hydropower projects towards which focused measures and policies may be directed. In all, these indicators will be helpful for sustainable development of RoR hydropower projects (large and small) in hydro rich Indian states in particular and similar regions throughout the world in general.

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